Computational Analysis of Foil Air Journal Bearings Using a Runtime-Efficient Segmented Foil Model

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Long Abstract

Introduction

Foil air journal bearings are an upcoming technology in high-speed rotating machinery and benefit from some major advantages compared to conventional rolling-element bearings. Most notably, the absence of solid-to-solid contact reduces both wear and power loss [1]. However, air bearing rotor systems may exhibit self-excited vibrations under certain conditions. As shown in [2], the insertion of a compliant foil structure into the lubrication gap seems to reduce this undesirable effect.

Currently, most foil models used for numerical investigations are based on one of two widespread approaches. The classical method neglects the segmentation of the foil structure and assumes it to act approximately as a homogeneous linear-elastic foundation (see [1]), whereas numerous recent publications (see, e.g., [3]) rely on time-consuming FE models aiming at more realistic simulations.

The beam-based model presented in this paper is supposed to reproduce most of the experimentally known particularities (see [3]) in the static and transient behavior of the segmented foil structure, whilst being almost as time-efficient as the simple elastic foundation model.

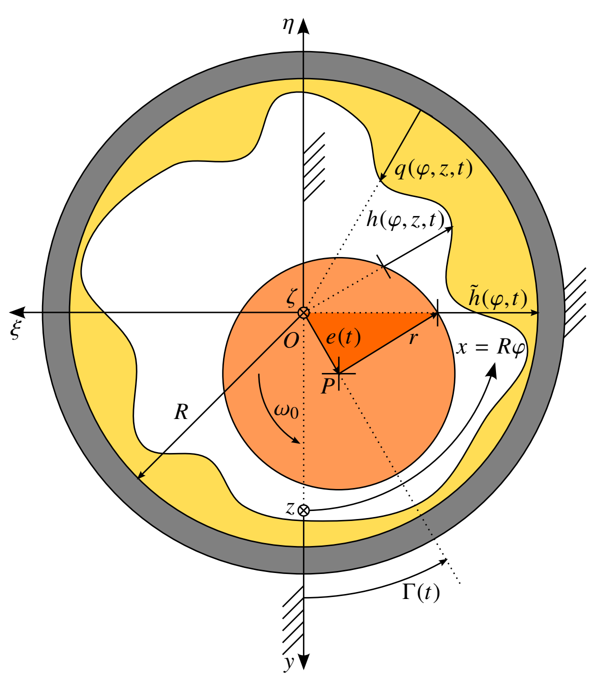


Figure 1. Sketch of the bearing model.

Bearing model

A sketch of the foil air journal bearing model considered in this study is depicted in Figure 1 (with greatly magnified clearance $C = R - r$ for better visibility). As stated by the well-known lubrication theory, the pressure distribution $p = p(\varphi, z, t)$ within the lubricant film of thickness $h = h(\varphi, z, t)$ is governed by the Reynolds equation for compressible fluids [4]

$$\frac{1}{\mu_0 R^2}\frac{\partial}{\partial\varphi}\left(ph^3\frac{\partial p}{\partial\varphi}\right) + \frac{1}{\mu_0}\frac{\partial}{\partial z}\left(ph^3\frac{\partial p}{\partial z}\right) = 6\omega_0\frac{\partial}{\partial\varphi}(ph) + 12\frac{\partial}{\partial t}(ph)\,. \quad (1)$$

The deflection of the compliant foil structure is represented by the generalized deformation field $q(\varphi, z, t)$. Depending furthermore on the journal position, i.e. $e(t)$ and $\Gamma(t)$, the effective film thickness is found to be approximately

$$h(\varphi, z, t) = C - e(t)\cos\left[\varphi - \Gamma(t)\right] - q(\varphi, z, t). \quad (2)$$

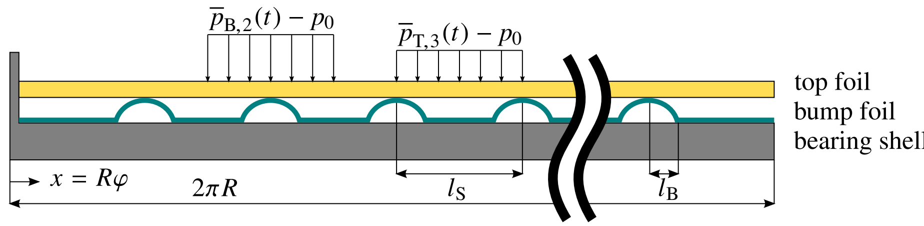


Figure 2. Foil model interacting with the averaged lubricant pressure.

Foil model

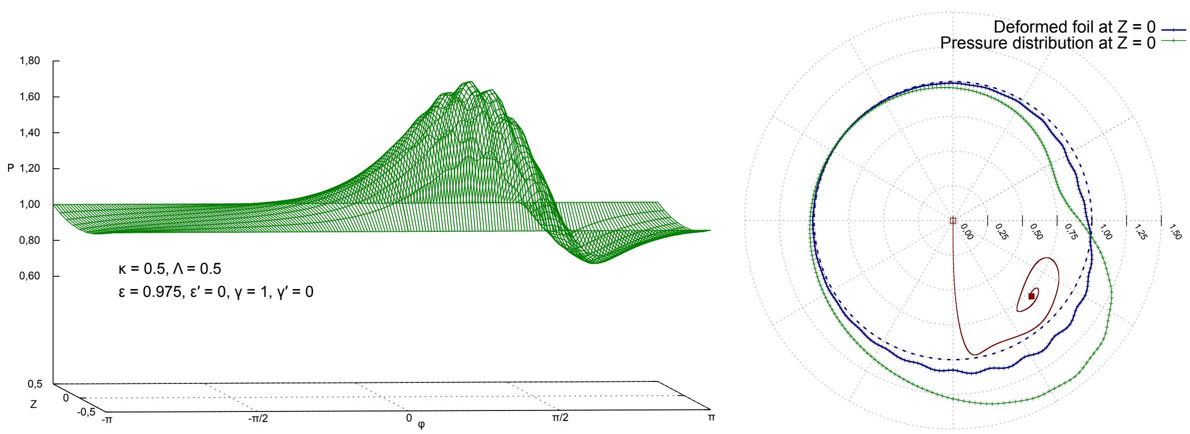
The foil structure is composed of a bump foil (N_B bumps) and a top foil. The latter interacts directly with the lubricant pressure which is averaged in axial direction, giving $\overline{p}(\varphi, t)$. Additionally, piecewise pressure averages (see Figure 2) in circumferential direction are defined: $\overline{p}_{B,n}(t)$ acting on the n-th bump and $\overline{p}_{T,n}(t)$ acting on the n-th top foil segment. Treating the segments separately as elastically supported beams with the flexural rigidity D_T, we obtain a piecewise deformation field (setting $x_n = R\varphi - nl_S$)

$$-q_n(\varphi, t) = \frac{\overline{p}_{T,n}(t) - p_0}{24 D_T} x_n^2 \left(l_S - x_n\right)^2 + 2\left(v_{B,n}(t) - v_{B,n+1}(t)\right)\left(\frac{x_n}{l_S}\right)^3 - 3\left(v_{B,n}(t) - v_{B,n+1}(t)\right)\left(\frac{x_n}{l_S}\right)^2 + v_{B,n}(t) \quad (3)$$

which depends on the bump displacements $v_{B,n}(t) = k_B^{-1}\left(\overline{p}_{B,n}(t) - p_0\right)$ with the bump stiffness k_B.

Analysis

A nondimensional and discretized form of Eq. (1) is implemented using a time integration scheme and coupled with both the foil model via Eq. (3) and a rigid rotor model. Simulations expose several effects that are due to the segmented foil structure and therefore cannot be observed with the simple elastic foundation model. Figure 3a represents a pressure distribution with characteristic local pressure drops resulting from the top foil sagging between the bumps. Further investigations reveal detrimental impacts on the load-carrying capacity resulting from this effect. As depicted in Figure 3b, the model permits us to perform time-saving transient simulations — results will be shown in the full paper.



(a) Pressure distribution in the lubrication gap.

(b) Journal trajectory (rigid rotor model).

Figure 3. Examples of characteristic simulation results expressed as nondimensional quantities.

References

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